

MEASURING SYSTEM FOR RECORDING ABSOLUTE ANGULAR  
OR POSITION VALUES

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Cross-Reference to Related Application:

This application is a continuation-in-part of U.S. application  
No. 10/200,901, filed July 23, 2002, which is a continuation-  
in-part of U.S. application No. 10/116,489, filed April 4,  
10 2002.

The present invention relates to a measuring system for  
recording absolute angular or position values.

15 Such a measuring system, which is suitable both for angular as  
well as position measurements, is well known from DE 195 05  
176 A1. This specification describes a linear PRC code  
(absolute encoding in the scale axis and one after the other  
in a narrow line with equal spacing of an additional  
20 incremental track) whose length is given by  $L = \frac{\text{the division}}{\text{bit value of the absolute code}}$ . The incremental track  
serves the purpose of increasing the accuracy of the  
respective absolute value to be determined.

25 With a division spacing of, for example, 20 to 30 $\mu\text{m}$  and a 12  
bit absolute track, total lengths of 20 $\mu\text{m}$  to 30 $\mu\text{m}$  \* 4096  $\cong$  82

to 123mm result. This maximum scale length is far too short for many purposes. If scale lengths of, for example, 4 to 5m are to be implemented, absolute codes of more than 18 to 20 bits are needed, as indicated in DE 195 05 176 A1.

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Such scales are complicated to manufacture. Moreover, the 18 to 20 photo-receivers must render the scale as distortion free as possible and this must be illuminated with light of sufficient intensity. In addition, complex signal processing is required in the evaluation electronics.

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Incremental length encoders for such a scale length are versatile as regards scale design and evaluation electronics, so that they are also used for absolute measurements. To do this, one or several reference marks are necessary, which must always be approached when the system is switched on or off. The measuring device is also susceptible to loss of position, therefore this must always be taken into account by approaching the reference marks to ensure the required accuracy. This is time-consuming, not always feasible and is preferred only for cost reasons over the rarely encountered and expensive absolute measuring systems.

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#### Summary of the Invention:

An object of the present invention is to provide a measuring system for recording absolute values, which can be used for

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large scale lengths, and which does not require a very large number of bits in the scale encoding with the associated disadvantages.

5 With the foregoing and other objects in view, there is provided in accordance with the invention, a linear measuring system for the recording of angular and position absolute values, where the scale includes a measurement track for generating absolute values which is recorded by an appropriate  
10 scanning head, wherein the scale with the measurement track is a structured material characteristic or a structured surface on a material, wherein the scale is composed of at least two segments which are identically created for the generation of absolute values and wherein at least one suitable track is  
15 provided on the scale for determining the absolute value of the particular segment reached by means of a further sensor arrangement and wherein means of switching are provided which use the absolute value of the segments and the calculated absolute value within the segment to provide the total  
20 absolute value for further processing.

According to another feature of the invention, the at least one suitable track is at least one part of the measurement track composed of one or more tracks.

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According to a further feature of the invention, the at least one suitable track is at least one parallel track applied onto the scale.

5 According to yet another feature of the invention, the particular segments are designed with the same code sections.

According to yet a further feature of the invention, the parallel track is designed for magnetic signal recording.

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According to yet another feature of the invention, the parallel track contains permanent magnetic segments.

15 According to yet a further feature of the invention, an auxiliary power battery outside and/or inside the further sensor arrangement is provided for emergency supply.

20 According to yet another feature of the invention, the measuring system comprises at least two identical and staggered sensors whose measured values are used for redundant signal evaluation by the external control system.

25 According to yet a further feature of the invention, the fundamental absolute measuring system is based optical, sound, ultrasound, magnetic, inductive, electromagnetic or capacitive measuring systems or a combination thereof.

According to yet another feature of the invention, the absolute value of the segment reached is determined by logical evaluation of the traversed segments from a defined starting position.

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According to another feature of the invention, the structured material characteristic is a patterned material characteristic.

10 According to another feature of the invention, the structured surface is a patterned surface.

According to yet another feature of the invention, the scale with the measurement track is a structure or pattern of a measuring object, the structure or pattern being provided  
15 substantially only in an operating range of sensors.

According to yet another feature of the invention, the scale with the measurement track is a machined surface structure of  
20 a material.

According to another feature of the invention, the scale with the measurement track is a lacquer layer structured with ultrasound.

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According to another feature of the invention, the scale is provided underneath a surface of a measuring object such that the scale can be detected by a sensor.

5 The linear scale in accordance with the invention may be produced at a reasonable cost for any length of linear measurement and is simple to use. The complete scanning sensor's components are suitable for universal application in angular and position measuring systems and can be used for any  
10 lengths of measurement. The design of the linear measuring device in accordance with the invention takes account of the wide range of requirements and produces a universal and cost-effective device design for even the most diverse of tasks.

15 The idea behind the invention is to use, for example, 12 bit absolute encoded segments, which for optical scanning systems are about 100mm in length, and a plurality thereof arranged in sequence produce the length of the scale. Advantageously these segments contain an absolute encoded track, preferably  
20 equipped with an additional incremental track running parallel for analog recording of the path in between, in order to produce a total absolute value of very high resolution. A 4m scale contains approximately 40 such identical absolute encoded segments, for example, in PRC code, the code design  
25 for the beginnings and ends of which is taken into account for the continuous signal evaluation. A 12-bit code, for example,

will result in 144 possible encodings, after which a cyclic transition to the next segment can take place.

In order to determine the absolute position as a whole, it is  
5 necessary to record the "number" of the particular segment.  
In accordance with the invention, this is done by recording the segments according to direction and position, and then identifying them logically from a defined starting position.

10 The segments must also be recorded when the main power is switched off, and therefore the consumption of energy or power needs to be low so that auxiliary power which is suitable for this purpose can be made available, for example via a battery. The power consumption of all of the previously known measuring  
15 systems for recording absolute values is far too high for this, typically between 20 mA and more than 200 mA, so that batteries cannot be used to provide the auxiliary power. According to the invention, therefore a further sensor arrangement with a suitable evaluation circuitry is provided  
20 which makes it possible to perform countable recording of segments while the associated expenditure and therefore the power consumption are kept as low as possible. The design and therefore the power consumption of this further sensor arrangement depend to a great extent on the type of recording  
25 of the absolute encoded segments to be performed.

If the absolute encoded segments are used for recording the number of the segments by means of the further sensor arrangement, this offers the advantage that the existing measurement track can be used. The sections, which are provided, for example, with a PRC code and designed as 12-bit absolute encoded sections, offer different possibilities of recording the number of sections using the further sensor arrangement. The PRC absolute track itself, for example, can be used by reducing the absolute recording to one single sensor, as described in EP 1102040 or US 09/716,338, and leaving out the additional evaluation of the incremental track so that the thereby simplified circuit arrangement for recording the sections requires as little auxiliary or battery power as possible.

The incremental track described above, which is advantageously arranged in parallel to the PRC track, is also suitable for the accurate recording of the segments by means of the further sensor arrangement. For this purpose, two sensors of the known simple type, for example, which are staggered by  $90^\circ$  ( $270^\circ$ ), can be used to record the  $360^\circ$  incremental division segment. Countable recording of the incremental segment is performed according to direction, and the resultant length of the absolute segment (in the case of a 12-bit code, for example, this corresponds to 4096 increments) is recorded and used to evaluate the total absolute value.



There are different ways in which the absolute segments can be encoded. A simple version is, for example, a segment generating a sin/cos signal of  $360^\circ$  over the entire length (for example, through magnetized N/S segments), which can be  
5 divided with a correspondingly high resolution of between 8 bits and 12 bits and more by interpolation. Such absolute segments arranged in sequence can also be used in a simple way for power-saving recording of particular absolute segments by using, for example, the well-known evaluation circuits with  
10 two sensors which are staggered by  $90^\circ$  in the further sensor arrangement.

The absolute measuring system can also be applied advantageously where the measuring object does not have  
15 specifically applied markings but a structured or patterned material or a structured or patterned surface, and thus has a measuring scale with a measurement track. The structured/patterned surface or structured/patterned material need only be provided in the operating range of the sensors  
20 that are employed and may therefore only include a part of the measuring object. Measuring methods are known, which, for example, evaluate in relative movement the determined periodic signals of, for example, paper-, steel- and plastic bands etc. via suitable sensors and optical components with light rays.  
25 German Patents No. DE 2 163 200 C2 and DE 2 133 942 disclose such measuring methods whereby the latter even evaluates non-

determined and statistically fluctuating measuring signals of, for example, moving sheet metal bands via the correlation method.

5 Such measuring objects are either suitably determined in their material characteristics, for example, in manmade materials such as plastic materials, or the surfaces machined by sanding, grinding, fine profiling etc. for example, of pistons, have the necessary structures for an appropriate  
10 measurement track for evaluation. In German Published, Non-Prosecuted Patent Application No. DE 3 418 854 A1, the desired structures in lacquer or resist layers are optically pre-structured via ultrasound and firmly fixed in the material via ultrasound, as well as checked afterwards via ultrasound using  
15 appropriate measuring techniques. The structures or patterns for a measurement track can be provided underneath the surface of the measuring object such that the structures or patterns can be detected by the sensors. There are thus many physical measuring methods (for example, electromagnetic radiation,  
20 laser light, sound etc.) in order to evaluate corresponding measuring signals, e.g. via the surface of moving measuring bodies as a scale having measuring tracks, by using appropriate sensors.

25 For each individual absolute segment and for each of its possible designs, there are several methods and designs which

are suitable for the further sensor arrangement in order to record the number of segments in a more or less power saving way. The limits to the lowest power consumption are set here by the absolute encoding selected, and these are critical to many applications with limited availability of auxiliary power. In particular in the case of applications which require battery operation over 5 ... 10 years without recharging, the required power must be decreased to a few  $\mu\text{A}$ . In order to ensure this as far as possible, additional measures are provided by the invention as will be described in the following.

In accordance with a further design of the invention there is, in addition to the absolute encoded segments, a track, which permits the recording of the segments in 4 sections by interacting with, for example in its simplest design, two switch sensors, thus clearly determining the position even for extremely high process speeds. In its simplest type the track is provided with a symmetrical dark/light track for optical systems, or, for magnetic scanning, with a structure having approximately 50% of the sections magnetic and non-magnetic, and is advantageously staggered by 25% of the segments at the beginning and end of the encoded track, respectively. It is recommended to record the track magnetically which, by means of a permanent magnet, can provide the auxiliary power for the sensors used for this purpose, and which favors battery

operation for signal processing and data storage due to the minimal power consumption. This detection system is also very robust and resistant to dirt. The auxiliary power battery is required to store the absolute value of the segment, to enable  
5 secure recording of position immediately after switching on the supply voltage. This also guarantees the correct absolute value of the segment when the mains power is switched on again, if the movable device is adjusted by hand when there is no mains power. The individual segments and their numbers are  
10 co-recorded as absolute values on the parallel track and thus create the absolute value when the equipment is switched on again.

The absolute value generation in each particular segment  
15 achieved in this way - quite independent of the selected process used for absolute value generation - is supplemented by means of the countable recording of segments to form the total absolute value for any length of scale. The sensor components including signal processing are housed in the  
20 complete sensor. They are the same for a plurality of angular and position measuring systems and are therefore versatile in use. The scale can be created in "endless length", the required lengths of scale can simply be separated from it. Advantageously, the data exchange and parameterizing  
25 interfaces are also designed identical to those of the rotary and angular position encoders, in order to ensure the

advantageous end-to-end integration of the sensor systems in customer control systems with respect to start-up, use and service. Fully digital versions via SSI data exchange and parameterizing are especially advantageous in this respect.

5 Encoder systems, under real-time signal processing in particular, offer redundant sensor evaluation via parallel retrievable SSI pulse signals on several encoders - each with a separate data line - and may also be used in a linear measuring system in a very dirty environment (both for the  
10 sensor and for the scale).

Other features which are considered as characteristic for the invention are set forth in the appended claims.

15 Although the invention is illustrated and described herein as embodied in a measuring system for recording absolute angular or position values, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from  
20 the spirit of the invention and within the scope and range of equivalents of the claims.

The construction and method of operation of the invention, however, together with additional objects and advantages  
25 thereof will be best understood from the following description

of specific embodiments when read in connection with the accompanying drawings.

Brief Description of the Drawings:

5 Fig. 1 shows the structure of the scale;

Fig. 2 shows the scale with sensors;

Fig. 3 is a schematic view of an embodiment of a measuring  
10 system according to the invention;

Fig. 4 is a schematic view of another embodiment of a measuring system according to the invention;

15 Fig. 5 is a schematic view of a further embodiment of a measuring system according to the invention;

Fig. 6 is a schematic view of yet another embodiment of a measuring system according to the invention;

20 Fig. 7 is a graph illustrating a signal course over time; and

Fig. 8 is a schematic view of yet another embodiment of a measuring system according to the invention.

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Description of the Preferred Embodiments:

Fig. 1 shows a part of a scale 1 which is provided with a track 2 encoded with, for example, 12-bit absolute values. This means that the appropriate scanning head comprises an array of twelve scanning cells, each of which recognize a new absolute value after a movement of one increment. Three segments 1a to 1c are shown here, whereby only an extract of the central segment 1b can be seen. In one segment there are  $2^{12} = 4096$  distinct increments present, for example in PRC code. The total scale is made up of several segments 1a to 1c. An incremental track 3 is positioned below track 2, and is used to increase the accuracy of each of the particular values of the absolute track 2; it has the same total length as the scale. Both track 3 and track 2 form the absolute encoded segments and can be used, individually or in combination with the further sensor arrangement, for countable recording of the segments.

In addition to the said tracks according to the invention an additional track 4 of the same length as the segments can be provided, which is used to recognize and record the segments and is based on a defined starting position to logically determine the direction and position of the segments. Thus the "number" of individual segments can therefore be determined. In its simplest form, the track is equipped with a symmetrical dark/light track for optical systems, or, for a

track with magnetic evaluation, with 50% of the segments having either a magnetic or non-magnetic structure. It is important that at the transitional points from one segment to another, for example from 1a to 1b, a magnetic structure is present and is located staggered by approximately 25% of the segments. This is shown in Fig. 1 where, for the purposes of track 4, it may be assumed that segment 1b is shown in its entirety. Only by doing this can it be shown that 50% of the track is magnetic and 50% non magnetic. The track is scanned with, for example, two switch sensors, to determine clearly the point of transition. The switch sensors are positioned advantageously at a distance of approximately 25% of the segment. This allows recording of the 4 quadrants of the segments marked, for example with an x in Fig. 1, (2 times 25% magnetic, 2 times 25% non-magnetic), at approximately 2m/sec, even at a very high measuring speed of, for example, 10m/sec., which is certainly sufficient even for slow sensors such as Reed switches or pulsed magnetic sensors. This is important for the evaluation of the segments to be counted under all sorts of on/off switching operations of the supply voltage and for the logical composition of the absolute value using the segments and necessitates careful design. It is not intended to further explain here that higher sensor switch speeds would allow them to be located at much smaller distances than 25% of the segment, for example in an integrated module. Hence, the actual position is calculated from the absolute value of track



2, enhanced possibly by track 3, and the determination of the "numbers" of segments with track 4.

The term 'parallel track' shall also include those cases in which the encoding of the parallel track provided to determine the number of the segment superimposes the measurement track, and where the further sensor arrangement only record the encoding assigned to them.

Fig. 2 shows a side view of scale 1 with a number of segments, for example 1a to 1c. There are two staggered sensors S1, S2, whose measurement results are used for a redundant signal evaluation and are processed accordingly in the control system 6.

Fig. 3 shows the scale 1 with the sensor components and an exemplary signal processing, which includes the sensor 5. The further sensor arrangement 7 is supplied, together with the associated switching means 10 of the absolute values of the segments, from the mains power 12 as well as from an auxiliary power 13, such as a battery, such that during a mains disconnection the function is maintained and no segment measurement values are lost.

The measurement track 2, 3 detected by the scanning head 8 results in the generation of the absolute values 9 within the

segments and needs only function when mains-power is provided. The two absolute values 9 and 10 are consequently used for generating the total absolute value 11 which is provided by 14 for further processing wherein the defined starting position  
5 15 are taken into account.

Figs. 4 and 6 show various scales with absolute measuring tracks and the respectively assigned arrangement of the scanning head 8 for an absolute recording within the segment  
10 and the further sensor arrangement 7 for forming the absolute value of the segments. This signal processing is accomplished in the same manner as described above for the embodiment shown in Fig. 3.

15 Fig. 7 illustrates the operating mode of the exemplary advantageous scale shown in Fig. 6. The embodiment shown in Figs. 4 and 7 have already been explained in detail in the description above and therefore no further explanations are necessary.

20 Fig. 8 shows a structured surface as a suitable measuring track 17. The sectional view A illustrates the substantially same segments 1a, 1b, 1c of such a structure, that are produced for example by a mechanical processing of the  
25 material surface, such as a machining of the material. Such relief structures generate, in combination with suitable and

correspondingly arranged measurement sensors, the  
corresponding signals similar to the signals shown in Fig. 7.

Thus, such structured/patterned surfaces or

structured/patterned materials can in an advantageous manner

5 be used in the same way as the above-mentioned scale

embodiments of Figs. 1 to 7 for an absolute measurement of

angular and position values without requiring a separate scale

or scale disc. In particular when moving surfaces of, for

example, pneumatic or hydraulic piston movements are to be

10 determined in a sealed manner, scaleless measurements tracks

can be used in an advantageous manner. But even if scales are

separately used, structured material or surfaces that have

been processed such that they are structured allow producing

cost-effective embodiments of such coded measurement tracks.